Direct Calculation of Tuner Losses

Dave Birnbaum

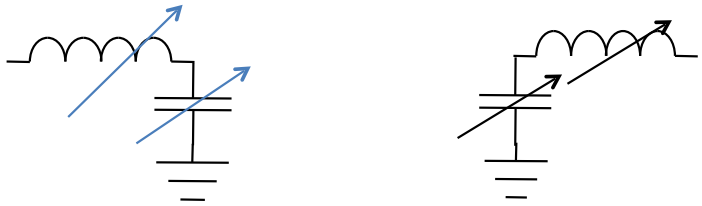
K2LYV

What, Why

- Amateurs are using a huge variety of antennas these days. Many of these need some sort of tuner to provide a good match to a transceiver.
- With the availability of fast computers and antenna modeling software (EZNEC, 4nec) many antenna designs can be modeled in detail which includes direct calculation of antenna impedance vs. frequency.
- Tuners are very good but not perfect.
  - Losses in inductors, voltage limits on capacitors
- It could be important to know the frequencies where an antenna could cause failures in the tuner.

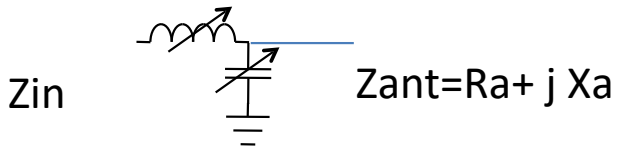
The L-network

- In principle any two (complex) impedances can be matched at one frequency by an L-network.
- I will limit this discussion to an L network with a capacitor shunt to ground and an inductor in series
  - Most (all) autotuners use this configuration
  - The analysis can easily be extended to any combination of elements i.e. two capacitors, two inductors, different shunt or series combinations.
- Two configurations differing on where the shunt element is



Solving for element values

- First consider circuit A:
- We want Zin = 50Ω



- Zin = $jXl + Zant * \frac{Zant * jXc}{Zant + jXc}$
- For match we need the real part of Zin=50 and the imaginary part = 0.
- Notice that the only element that can change the resistive part of the antenna to 50 ohms is the shunt capacitor. The function of the series inductor is to cancel any remaining complex component of the parallel antenna-capacitor combination.

Solution – ideal components

- Solving the equations for the apparent impedance gives values for Xc and Xl:
- Easier to solve for admittance of capacitor, Bc (Bc = 1/Xc)
  - Find value(s) of Bc that make the R component 50 ohms

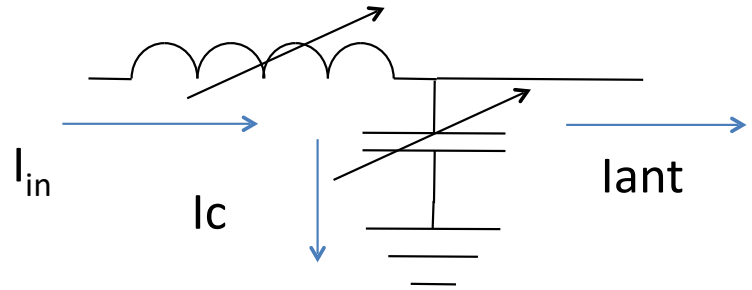
$$Bc = \frac{Xa \pm \sqrt{Ra/50}\sqrt{Ra^2 + Xa^2 - 50Ra}}{Ra^2 + Xa^2}$$

- The value of the series inductor is found by setting Xl to cancel any remaining capacitive reactance:

$$Xl = \frac{1}{Bc} + \frac{50Xa}{Ra} - \frac{50}{Bc * Ra}$$

We can calculate currents & voltages

- Assume some “standard” power – I use 100 W



- I_{in} is easy –
  - Notice all input current flows through the inductor in this configuration
  - Since effective impedance is 50Ω current is 1.414A
- I_{in} splits between shunt capacitor and antenna:

$$Ic = \frac{Za}{Za + jXc} \qquad Ia = \frac{jXc}{Za + jXc}$$

Correction for “real” components

- Since the components of the matching network are good, i.e. High-Q, we can usually safely assume that adding the resistive parts will not change things very much
  - But if series resistive component is more than about 10% of antenna resistance, add series resistive component and re-solve
  - Use ideal currents for calculations
  - jXc -> Xc/Qc + jXc; jXl -> Xl/Ql+jXl
  - Most losses in inductor
  - Voltage on capacitor can be a problem
- Current Iin splits between capacitor and antenna:

$$Ic = Iin * \frac{Za}{Za + jXc} \qquad Ia = Iin * \frac{jXc}{Za + jXc}$$

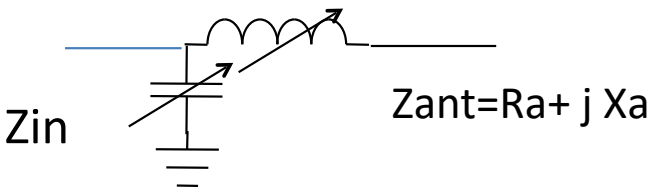
- So we have:

$$Vc = jXc * Ic \qquad Pl = Il^2 * \frac{Xl}{Ql} = 2Xl/Ql$$

Alternate configuration

- Similarly for circuit B:

$$Zin = \frac{(Za + jXl) * jXc}{Za + jXl + jXc}$$



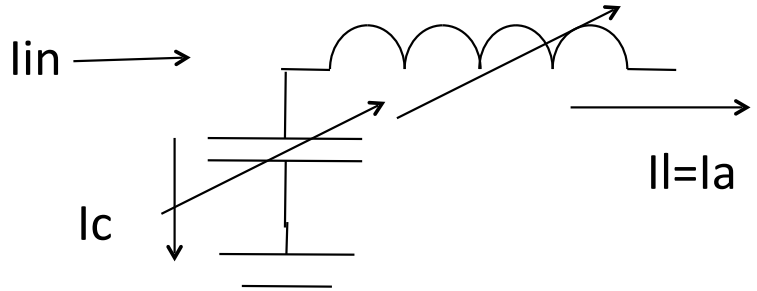
- Again we want Zin=50+j0, so solve for Re(Zin)=50 and Im(Zin)=0
- Result:

$$Xl = \pm\sqrt{Ra * (50 - Ra)} - Xa$$

$$Bc = \frac{1}{Xc} = \pm\frac{\sqrt{(50 - Ra)/Ra}}{50}$$

- Note: This can only be used when resistive component of load is ≤ 50Ω

Calculating currents and voltages



- Iin splits between capacitor and inductor + antenna

$$Ic = \frac{Za + jXl}{Za + jXl + jXc} \qquad Ia = Il = \frac{jXc}{Za + jXl + jXc}$$

- Adding lossy parts we get:

$$Vc = jXc * Ic \qquad Pl = Il_{rms}^2 * \frac{Xl}{Ql}$$

Some Examples

- Short (18 ft) vertical on 80M
  - Za = 17-j1945
  - For match L= 89µH, C=809pF
  - 100 W in, Pinduc=25W, Vc=71V
    - Are the toroids in your rig's antenna tuner big enough to dissipate 25 W?
- End fed 45' wire w/o balun at 10.1 MHz
  - Za=334-j572
  - For match L=3.96uH, C=39.8pF
  - 100W in, Pinduc=1.8W, Vc=362V
    - Adding 4:1 or 9:1 balun lowers Vc but not much effect on Pinduc
- In general, worst case is low Rant and/or high negative (capacitive) Xant.
- Note that transmission line between antenna and tuner may transform a not so bad impedance to a "bad" one.

Implementation

- I have implemented the above calculations in a Python program.
  - Implementation example rather than finished program – simple U/I etc.
  - Can run with manual or read data from file
- Why Python?
  - Simple language to learn
  - Handles complex numbers natively
  - Free compiler/IDE
  - Large number of free extensions and libraries, e.g. serial control, plotting, much more

What about the T network?

- While most of the autotuners are L-networks, many manual tuners use a T-network configuration (most common is shunt inductor between two series capacitors)
- While one can calculate the input impedance presented by any given antenna, finding the “right” setting for the tuner is not simple
  - Three variables to solve two equations means that there are multiple settings that will give a match
  - Not all settings are equal as far as efficiency e.g. coil losses, capacitor voltages.
  - Analytic solution replaced by optimization
    - probably to find lowest power loss of settings that give a match.

Some final comments

- If you're going to model your antenna, model your tuner too.
- Consider all combinations of L-networks: two inductors, two capacitors, series capacitor/shunt inductor.
- Note that you can run this "backwards:
  - If you know values of L network components that give a match, you also know the impedance at the tuner input
    - You need to have a way to know values of L,C at each setting
  - If the tuner isn't at the antenna, you can use transmission line equations to correct for intermediate transmission line
  - See Belrose QST Sept. 2006, p. 56 H&K note